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PERMO-CARBONIFEROUS CLIMATIC CHANGES IN SOUTH AMERICA

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INTRODUCTION

The presence in Argentina and Brazil of representatives of the Lower Gondwana, or *Gangamopteris* flora has for some years been definitely recognized through the small collections examined by Professors Zeiller[1] and Kurtz.[2] More recently, however, the Coal Commission of Brazil has placed in the writer's hands a number of fossil plant collections which, though lacking much both in quantity and preservation, are definitely fixed stratigraphically, while embracing a considerable vertical range.

The new material, from the coalfields, chiefly of the states of Santa Catharina and Rio Grande do Sul, in Brazil, not only confirms the presence in that country of the Lower Gondwana flora, but it also throws new light on the geographical relations and climatic changes in this quarter of the earth during Permo-Carboniferous time. The purpose of this paper is particularly to call attention to some of the physical conditions indicated with more or less distinctness by the fossil floras, and briefly to state the conclusions drawn or opinions entertained by the writer in an attempt to account for certain changes in climate.

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[1] *Comptes Rendus*, Vol. CXXI, 1895, p. 961; *Bull. Soc. géol. Fr.* (3), Vol. XXIII, 1896, p. 601.

[2] *Rev. Mus. de la Plata*, Vol. VI, 1894, p. 125; *Bull. Soc. géol. Fr.* (3), Vol. XXIV, 1896, p. 466.

The stratigraphical series in the coal basins of the state of Santa Catharina as published by Dr. I. C. White, late chief of the commission, is essentially as follows:[1]

Santa Catharina System:

São Bento Series:	Serra Geral eruptives. Botucatú sandstones, great cliffs of red, gray, and cream-colored sandstones. Rio do Pasto red beds, with fossil reptiles (*Scaphonyx* and *Erythrosuchus*) and fossil trees.
Passa Dois Series:	Rocinha limestone. Estrada Nova gray and variegated shales with cherty concretions, and sandy beds. Iraty black shale, *Mesosaurus* and *Stereosternum.*
Tubarão Series:	Palermo shales. Rio Bonito shales and sandstones, with coal measures and Gangamopteris (Glossopteris) flora. Orleans conglomerate. [Glacial] Yellow sandstones and shales to granite floor.

SYNOPSIS OF THE PALEOBOTANICAL DATA

On the side of the fossil plants it will be possible to give in this place only an enumeration of the species, with references to their stratigraphical position in Brazil. For the descriptions and other taxonomic data relating to the species the reader is referred to the report of the commission. In the following list[2] the species characteristic of the Gondwana series in other continents are marked by an asterisk (*), those clearly representing Gondwana types but comprising forms previously unknown are designated by the double asterisk (**), those generally regarded as proper to the Permo-Carboniferous of the Northern Hemisphere by a dagger (†), while those of mixed distribution or of unascertained geographical significance are indicated by the double dagger (††).

Rosellinites Gangamopteridis D. W.**; Hysterites brasiliensis D. W.**; Equisetites calamitinoides D. W.††; Schizoneura ? sp.**; Phyllotheca Griesbachi

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[1] *Science*, Vol. XXIV, No. 612, 1906, p. 377.

[2] *Reinshia australis* Bertr. & Ren. var. *brasiliensis*, which is included in the descriptive memoir, is here omitted, since from evidence kindly communicated by Dr. Derby it appears probable that the specimens in the Brazilian Exhibit at the St. Louis Exposition were first brought to Brazil from Australia.

Zeill.*; Phylotheca Muelleriana D. W.**; Phylotheca (?) sp.**; Lycopodiopsis Derbyi Ren.††; Lepidodendron Pedroanum (Carr.) Zeill.††; Lepidophloios laricinus Sternb.†; Sigillaria Brardii Brongn.†; Sigillaria austarlis D. W.††; Sigillaria sp.††; Sigillaria (?) muralis D. W.††; Sphenopteris hastata McCoy?*; Sphenopteris sp.**; Psaronius brasiliensis Brongn.**;[1] Neuropteridium Plantianum (Carr.) D. W.[1] (*N. validum*)*; Glossopteris Browniana Brongn.*; Glossopteris indica (Brongn.) Schimp.*; Glossopteris ampla Dana.*; Glossopteris occidentalis D. W.**; Glossopteris sp.**; Vertebraria sp.**; Gangamopteris obovata (Carr.) D. W.* (*G. cyclopteroides*); Ottokaria ovalis D. W.**; Arberia minasica D. W.**; Derbyella aurita D. W.**; Noeggerathiopsis Hislopi (Bunb.) Feist.*; Cardiocarpon Seixasi D. W.††; Cardiocarpon Moreiranum D. W.††; Cardiocarpon Oliveiranum D. W.††; Cardiocarpon Barcellosium D. W.††; Voltzia? sp.††; Dadoxylon Pedroi Zeill.††; Dadoxylon nummularium D. W.††; Dadoxylon meridionale D. W.††; Carpolithus? sp.††; Hastimima Whitei D. W.**

FLORAS AND THEIR CLIMATIC SIGNIFICANCE

The examination of the stratigraphical occurrence of the species just enumerated indicates that at the base of the Brazilian coal measures we have a Lower Gondwana flora essentially identical with that found in the corresponding beds in India, Australia, and South Africa; and that in the higher beds we have the introduction of Northern Permo-Carboniferous types which appear to indicate the progress of a great climatic change. The data bearing on this matter are briefly summarized in the following paragraphs:

Basal, Lower Gondwana Flora.—The only species collected from a shale lens but 6 meters above the unconformable crystalline floor of the coalfield is *Gangamopteris obovata* (*G. cyclopteroides*), one of the most characteristic as well as earliest of the Lower Gondwana plants.[2] The next higher plant bed of importance lies at a horizon but 55 meters above the granite floor near Minas, state of Santa Catharina, where we find, in the Minas formation, *Rosellinites Gangamopteridis*, *Hysterites brasiliensis*, *Phyllotheca Griesbachi*, *Phyllotheca Muelleriana*, *Phyllotheca* sp., *Glossopteris Browniana*, *Vertebraria* ?, *Gangamopteris obovata*, *Arberia minasica*, *Derbyella aurita*,

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[1] Not represented in the collection.

[2] On account of its strictly Paleozoic distribution, wide geographical range, ready recognition, and pre-eminent characterization of the Lower Gondwana series GANGAMOPTERIS has been substituted by the writer for "*Glossopteris*," previously used to designate the flora, but which is unsuited therefor on account of its transgression in the Mesozoic and its nomenclatorial inapplicability.

Noeggerathiopsis Hislopi, *Cardiocarpon* (*Samaropsis*) *Seixasi*, *Cardiocarpon Moreiranum*, *Voltzia* ? sp., and *Hastimima Whitei.*

The flora enumerated above belongs to the early typical GANGAMOPTERIS or Lower Gondwana flora. The distribution of its identical or related species in other continents indicates contemporaneity with the Ecca shales of South Africa, the upper coal measures of New South Wales, the upper marine coal measures of Tasmania, and the Karharbari beds of India. Concomitantly the underlying Orleans conglomerate of the Brazilian region is correlated with the Dwyka conglomerates of South Africa, the Baccus Marsh conglomerates and their equivalents in Australia and Tasmania, and the Talchir conglomerates of India.

Cold climate of the basal flora.—The appearance of the GANGAMOPTERIS flora in its simple and relatively pure condition immediately above the basal bowlder beds of South America in a way exactly similar to its occurrence in India, Africa, and Australia bears irrefragable evidence of a corresponding similarity of the accompanying climate. The consequent inference that glacial conditions had preceded the flora in South America is verified by Dr. I. C. White's studies of the basal bowlder beds and conglomerates of the Santa Catharina series in which he finds distinctly glaciated material. The earlier suggestion by Dr. Orville A. Derby[1] that the basal Permo-Carboniferous bowlder beds of Brazil were associated with glacial activity in that continent thus finds a double confirmation.[2] As to the reality of glacial action during Permo-Carboniferous time it may be added that, notwithstanding the great differences of opinion as to causes, the work of ice, especially in South Africa where the glaciation was on a truly great scale, has been so convincingly demonstrated over large areas as no longer to be questioned or require the citation of further proof.[3]

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[1] *Waagen, Rec. Geol. Surv. India*, Vol. XXII, Pt. 2, 1889, p. 69.

[2] In this connection it may be of interest to note that identical conclusions as to Paleozoic glaciation in Brazil were reached by Dr. White and the writer, one on purely geological evidence, the other on strictly paleobotanical data, each entirely without knowledge of the facts or opinions of the other.

[3] See T. W. E. David, *Quarterly Journal of the Geological Society of London*, Vol. LII, 1896, p. 289; Wm. M. Davis, *Bulletin of the Geological Society of America*, Vol. XVII, 1906, p. 47; Frech, *Lethaea Palaeozoica*, Vol. II, Lief. 4, 1902, p. 572; and Chamberlin and Salisbury, *Geology*, Vol. II, 1906, p. 538.

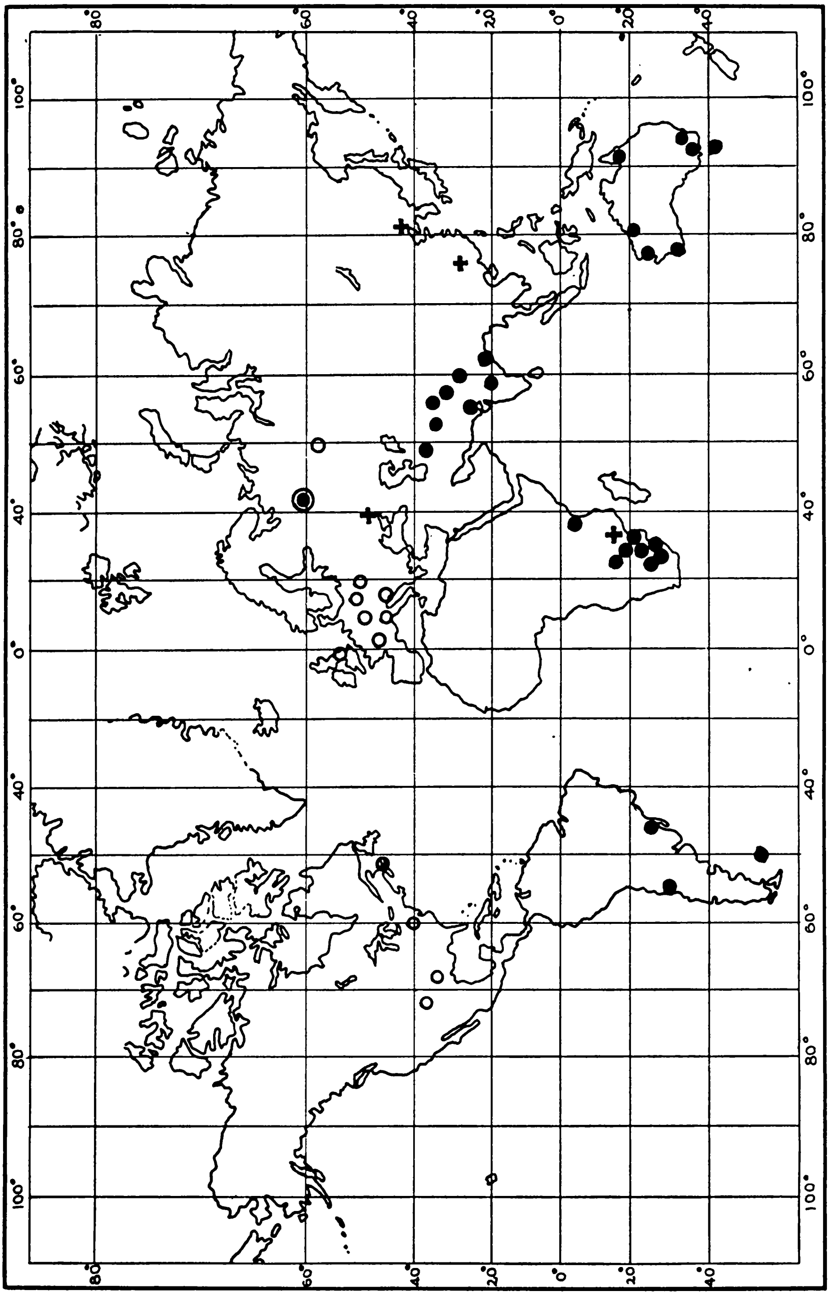

FIG. 1.—Regions in which the GANGAMOPTERIS flora has been found are shown by solid black rings. Several neighboring regions of our higher Coal Measures flora are shown by crosses. General regions of the Cosmopolitan Permian flora are indicated by white rings. The dark circle in the larger light ring designates mingling of Cosmopolitan and GANGAMOPTERIS types in the later Permian

The regional refrigeration which drove back or exterminated the Northern Permo-Carboniferous flora undoubtedly constituted the principal environmental cause in the development of the GANGAMOPTERIS flora. In the Greta series of New South Wales this flora appears to have been interglacial. The absence of cosmopolitan northern types, particularly of the Lycopods, from the beds immediately following the glacial conglomerates in Brazil, as well as in other areas of the pure GANGAMOPTERIS flora can have been due only to the inhospitability of the environment to those types at this time.

Beginning of return of northern types.—Although subsequent collections may show a lower range for some of the types, it would appear from the data at present available that in the Brazilian basins the first traces of Northern Permo-Carboniferous elements are met at 120 meters above the granite where we find Lepidophytic megaspores. At 135 meters above the granite—i. e., in the Nova Estrada formation—the same form of spores is mingled with cortical fragments and leaves of *Sigillaria.* With them are *Equisetites calamitinoides, Schizoneura* (?) sp., *Sigillaria australis, Sphenopteris hastata* (?), *Glossopteris indica, Glossopteris ampla, Glossopteris occidentalis, Noeggerathiopsis Hislopi,* and *Cardiocarpon Oliveiranum.* The flora as a whole is still overwhelmingly Southern, most of the species being characteristic of the older Gondwana series.

Continued climatic amelioration.—From a group of coals situated about 157 meters above the granite floor, and about 100 meters below the top of the Iraty black shale, which forms the base of the Passa Dois series, were collected *Lepidophloios laricinus, Glossopteris Browniana, Glossopteris indica, Glossopteris* sp., *Vertebraria* (?) sp., *Gangamopteris obovata, Noeggerathiopsis Hislopi, Cardiocarpon Moreiranum* and *Cardiocarpon Barcellosi,* while a carbonaceous stratum a little higher is largely composed of the remains of *Lepidodendron Pedroanum, Lepidophloios laricinus* and *Sigillaria Brardii.* The collections from these horizons are quite small and insufficient in species; but they are ample enough to show conclusively the presence of Lepidophytic elements typical of the Northern Permo-Carboniferous flora mingling with the GANGAMOPTERIS flora. It is interesting to note that at the level of the last-mentioned coal the Lycopods again establish their pre-eminent part as great coal-makers.

The climatic cycle.—So far as is known the floras preceding the period of Permo-carboniferous glaciation in India, Australia, South Africa, and South America were essentially identical with those of the northern hemisphere. The phytiferous strata as yet brought to light show the presence of the cosmopolitan or northern Lower Carboniferous flora in Argentina and Australia, of a Middle Coal Measures flora in the Heraclea basin in Asia Minor, and of a Stephanian flora (probably Upper Conemaugh or Monongahela in age), in the vicinity of Tete, on the Zambesi, in what was later the territory of the GANGAMOPTERIS flora in South Africa. The extermination of the northern, or cosmopolitan flora from the regions of the pure GANGAMOPTERIS flora can have been due only to the causes producing the glacial refrigeration and the GANGAMOPTERIS flora itself in those portions of the earth. The presence of a Sigillaria in the Ecca beds of South Africa, and the invasion by the above-named Lepidophytes in Brazil shows at once not only an amelioration of the climate sufficient for the return of some of the northern elements, but also that the extent of the land areas was such as to make their return possible. In fact, it is probable that no oceanic barrier existed to prevent free access of the northern types at any time during the period of cold. It is important to note that these hardy invaders from the northern flora which, under the influence of ameliorating climatic conditions were the first able to regain a foothold in the lost territory, belonged to the Lepidophytes, or Lycopodineous group.

It thus appears that in South America, as in South Africa, the Lepidophytes were the first to mingle with the flora which succeeded the glacial climate, the invaders being apparently in greater force in South America.[1] The greater variety as well as the far greater numerical representation of the Northern Lycopod elements in the Brazilian area may be due either to relative nearness to the border of the refrigerated area, or to a more rapid and well-marked moderation of the climate.

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[1] Bodenbender reports the presence of *Lepidophloios laricinus*, *Sigillaria Brardii*, *Pachypteris*, and *Walchia* in Argentina. As to *Cardiopteris polymorpha*, *Adiantites antiquus*, and *Rachopteris* (Lower Carboniferous types), and *Lepidodendron selaginoides*, *L. aculeatum*, and *L. Veltheimianum* (Lower coal measures species) also reported by him there is room for doubt concerning either the identity of the plants or their relations to the GANGAMOPTERIS flora. See *Bot. Acad. Nac. Ciencias, Cordoba*, Vol. XVII, 1902, p. 203.

Evidence of equable climate during Passa Dois deposition.—The fossil-plant material collected from higher horizons of the Brazilian coal measures unfortunately consists only of fossil stems; but these furnish almost unmistakable evidence of a mild and equable climate. From beds near the top of the Tubarão series, in Rio Grande do Sul, not far above the horizon last mentioned a gymnospermous type, *Dadoxylon* (?) *meridionale*, was collected. Another horizon somewhat higher, or about 75 meters above the base of the Passa Dois series, in the same state, furnished *Dadoxylon* (?) *nummularium* and a tree Lycopod of large size, *Sigillaria* (?) *muralis*. Still another fossil Lepidophyte, *Lycopodiopsis Derbyi*, was found at 155 meters above the Iraty black shale in the state of São Paulo. The Iraty black shale, which has been definitely traced by Dr. White throughout the region, is probably the source of the *Dadoxylon* (?) *Pedroi* Zeill., and of Brongniart's *Psaronius brasiliensis*. It is also the horizon of Cope's *Stereosternum tumidum* as well as of the *Mesosaurus brasiliensis* McGregor, collected by Dr. White.

Even more importantly significant than the presence of the arborescent Lycopods, from the climatic standpoint, is the complete or almost total absence from the various fossil woods of all trace of annual rings. On the other hand annual rings are conspicuously developed in the trees described by Arber[1] and Shirley[2] and found associated with the pure GANGAMOPTERIS flora in beds overlying the glacial conglomerates in New South Wales and Queensland. The sensible abatement of climatic rigor indicated by the appearance of the Lycopods in the upper part of the Tubarão series in Brazil is thus confirmed by the uninterrupted growth in the fossil trees from the still higher beds, during whose deposition there appear to have been no marked seasonal changes of climate. The presence of the large Lycopods and of the Psaronius trunk in the Passa Dois series warrants the expectation that further search will reveal a pteridophytic and gymnospermous flora closely related to the contemporaneous

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[1] *Catalogue of the Fossil Plants of the Glossopteris Flora in the Department of Geology, British Museum,* 1905, p. 191.

[2] *Geol. Surv., Queensland,* Bull. No. 7, 1898, p. 14.

Northern Permian flora[1] and perhaps grown under climatic conditions but little dissimilar to those prevailing to the northward.

The large tree Lycopods and the Psaronius are sufficient evidence of the Paleozoic age of the environing rocks, and, therefore, of the greater part of the Passa Dois series. Likewise the occurrence of *Lycopodiopsis Derbyi* at the much higher horizon furnishes good ground for anticipating that the upper part also of the series will fall within the Permian limits. But the presence in the Rio do Pasto beds of Erythrosuchus and of *Scaphonyx Fischeri*, regarded as closely related to Euskelesaurus, of the Stormberg beds in South Africa, argues for the Triassic age of the red beds and eruptives of the succeeding São Bento series.

SUMMARY OF THE CLIMATIC CHANGES

Briefly summarized, the paleobotanical evidence now in hand, though very incomplete, goes to show:

1. The occurrence of the cosmopolitan or world-wide floras in various parts of the southern land areas up to a point somewhere in the Upper Coal Measures or upper Stephanian; and, consequently, a corresponding uniformity or equability of climate in both the northern and southern regions.
2. The presence, at the base of the Brazilian coal measures, of a pure Gangamopteris flora essentially identical with that found in beds following the glacial deposits of India, Australia, and South Africa, and undoubtedly existent under approximately identical climatic conditions.
3. Some moderation of the climate at an early date so as to permit the immigration of a few of the hardier Lycopodineous types from the contemporaneous Northern or "cosmopolitan" Permo-Carboniferous flora.
4. The restoration of an equable Permian climate in southern South America permitting the invasion of other Northern pteridophytic types and the growth of gymnospermous trees without annual rings.[2]

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[1] The Psaronius perhaps belongs to the Cladophleboid group of Pecopterids.

[2] The close of the Permian in the Brazilian basins appears to have been marked by deposition of variegated shales and cherts indicating oxidization and probable retreat of the sea, comparable to the geological phenomena of the time in other parts of the world.

The period from the deposition of the lowest coals overlying the glacial bowlder material to the return of the Lepidophytes is believed by the writer to have been not long.[1] It seems probable that the return of an equable climate was as early as the beginning of the Damuda Series of the Gondwana System, or as the early Zechstein (Upper Permian) of the northern system.

THE GANGAMOPTERIS PROVINCE

The GANGAMOPTERIS flora appears to have flourished in a state of relative purity in the Permo-Carboniferous coalfields of India; in Queensland, New South Wales, Victoria, and Tasmania, in the Australian region; in German and Portuguese East Africa, Portuguese South-East Africa, Rhodesia, Zululand, the Transvaal, the Orange River Colony, Natal and Cape Colony in South Africa; and in Argentina and southern Brazil in South America. It appears to be present, perhaps in a less pure condition, in Kashmir, Afghanistan, and Persia, while a number of its characteristic elements mingled with northern types are found in the Upper Permian (Zechstein) of northern Russia and in the Altai Mountains. The territory of the pure or typical GANGAMOPTERIS flora may be termed the GANGAMOPTERIS Province. It conforms for the most part to the geographical, though not the geological, limits of the "Glossopteris Province" as the latter was proposed and defined by Professor Zeiller.[2]

The GANGAMOPTERIS or "Gondwana-land" continent.—The GANGAMOPTERIS flora is predominantly a terrestrial flora of somewhat highly varied composition. Hence the occurrence of this flora in great uniformity, including an extraordinarily high degree of specific identity, and in relative purity, contemporaneously in India,

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[1] In Australia the more rigorous climate seems to have prevailed longer, with greater deposition of coal measures and with recurrence of glaciation. The Brazilian records may pertain only to the later of the ice extensions, or, on the other hand, regional subsidence or other related causes may sooner have brought amelioration in this quarter of the globe.

[2] *Rev. gén. d. science*, 8^{e} *année*, 1907, p. 5. The GANGAMOPTERIS province embraces the regional distribution of the original or typical flora, while at the same time concerning only beds of Paleozoic age, thus escaping the regions of Mesozoic migration and mingling of the genus *Glossopteris* and several of its early associates with the northern post-Paleozoic flora. The genus Gangamopteris appears not to have survived the Permian.

Australia, South Africa, and southern South America, leaves no recourse but to conclude that the land surfaces over which it extended were in such continuity, or intimate geographical relation, as freely to permit the migration of the flora, practically *in toto*, between all these quarters of the globe.

The regions in which remains of the GANGAMOPTERIS flora have already been brought to light, are roughly indicated on the accompanying map, Fig. 1. The disposition of these areas, chiefly in the Southern Hemisphere, and their geographical relations to the present Antarctica, point strongly to the inclusion of the latter as an important part of a great continent or aggregate of very closely proximate land masses freely traversed by the GANGAMOPTERIS flora. A relationship of the Antarctic lands to the southern continents is still indicated to a certain extent by the submarine topography. Their efficiency as a bridge in Permian time is almost beyond question; and it is, perhaps, reasonable to assume that they are parts of a great continental aggregation, essentially constituting, in a broad sense, a greater "Gondwana-land," of which Australia and southern South America were perhaps but lobes.

At this great length of time, since the Paleozoic, and under the conditions of lack of Antarctic geological information a delineation of southern continental outlines is largely mere guesswork. It does not appear to the writer as necessary or even justifiable greatly to interfere with the main basins of the south Atlantic Ocean or seriously to threaten the existence of the Indian Ocean. The oceanic displacements involved in postulating so great southern land masses would seem to be in part compensated by the smaller proportions of the Permian land areas not only in South America, but in the other continents.

The continued efficiency of the Antarctic land connection in Mesozoic time is attested by the relations of both land plants and vertebrates in the Southern Hemisphere. As bearing distinctly on this subject from the paleobotanical standpoint one need cite only the occurrence of the Rajmahal flora in Argentina as reported by Professor Kurtz.[1] The great extent of the land surfaces, whether combined in a single continent or included in several very closely situated land masses comprising the greater "Gondwana-land" of Permian time is also indicated by the vast areas of freshwater sediments unconformably laid down in the Indian, South African, and South American regions.

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[1] The intimate relationships of the Mesozoic and even of the Tertiary vertebrates of Patagonia to those of the eastern hemisphere have been abundantly shown by Professors Ameghino and Scott.

AGE OF THE GANGAMOPTERIS FLORA

It has been shown that the GANGAMOPTERIS or Lower Gondwana flora dates from the time of the glacial bowlder conglomerates—i. e., from the glacial period itself. Though many geologists and paleontologists appear still to disagree as to the geological time of this date, the criteria are sufficient to fix it within very close limits. The refrigeration cannot have antedated the flora at Tete[1] on the Zambesi, which is of middle or lower Stephanian age. So also the very late Coal Measures plants from the province of Shansi in China[2] and the flora representing a horizon close to the base of the Permian at Jantai in Manchooria[3] show no important climatic differences from the topmost Carboniferous floras of western Europe. On the other hand the mingling of GANGAMOPTERIS and Glossopteris species with *Callipteris*, *Lepidodendron*, and Zechstein animal remains in northern Russia[4] show that the flora was well established and becoming enriched at that time. The invertebrate fauna of the marine beds associated with the conglomerates in New South Wales are regarded by Frech[5] as Permian. The introduction of Lepidodendron, Lepidophloios, and Sphenophyllum in the GANGAMOPTERIS flora probably occurred before the close of the Rothliegende. It becomes most highly probable, therefore, that the refrigeration attending the birth of the flora was consequent to the great terrestrial uplift and withdrawal of the sea at the close of the Carboniferous or at the beginning of the Permian. The flora may accordingly be regarded as dating from the close of the former. The approximate equivalences of the formations, so far as recognized, in the at present detached areas of

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[1] Zeiller, *Ann. d. Mines* (2) Mem. Vol. IV, 1883, p. 594.

[2] Schenck, in Von Richthofen: *China*, Vol. IV, 1883, p. 209. Also Abbado, *Pal. Italica*, Vol. V, 1900, p. 125.

[3] Zalessky, *Verh. k. min. gesell.*, St. Petersb. (2), Vol. XLII, 1905, p. 385.

[4] Amalitzsky, *Comptes Rendus*, Vol. CXXXII, 1901, p. 591.

[5] *Lethaea palaeozoica*, Vol. II, Lief. 4, 1892, p. 590.

PERMO-CARBONIFEROUS FORMATIONS OF THE GANGAMOPTERIS PROVINCE

		India	Queensland	N. S. Wales	Victoria	Tasmania	S. Africa	Argentina	Brazil
Mesozoic	Cosmopolitan Flora	Umia Jabalpur Kota-Maleri Rajmahal Panchet	Ippswich Burrum c.	Up. Clarence Hawksbury (glacial) L. Clarence	Bellarine Coals	Upper Jerusalem	Cave ss. Red beds Stormberg	Cacheuta	São Bento Serra Geral Botucatú R. do Pasto
Up. Permian	Gangamopteris Flora	Damuda Raniganj Barakar	Bowen River Coals	Ballimore and Newcastle coal series	Baccus Marsh Series	Mersey and Porters Hill	Beaufort series	Red beds and sandstones	Passa Dois s. Rocinha ls. Gray & variegated sh. and ss. Iraty shale
L. Permian		Karharbari		Upp. Marine (glacial)			Ecca	Coals and shales	Tubarão Series Estrado N. Minas ss.
		Talchir (glacial)	Bowen R. Marine (glacial)	Greta coals L. Marine (glacial)	Baccus M. Conglomerate (glacial)	Upp. Marine with coals (glacial)	Dwyka conglomerate (glacial)	Basal conglomerate (glacial)	Orleans cgl. (glacial) ss. and sh. (local)
Pre-Permian	Cosmopolitan Flora	Unconformity	Unconformity L. Carboniferous Devonian	L. Marine Unconformity L. Carboniferous Devonian	Unconformity L. Carboniferous Devonian	Marine Unconformity	Unconformity Tete Stephanian Unconformity ? Witteburg Devonian	Unconformity Retamito Devonian	Unconformity Granites and Devonian

the Gangamopteris flora are indicated in the accompanying table. No attempt is therein made to include or show the equivalents of all the Mesozoic formations.

ORIGIN OF THE GANGAMOPTERIS FLORA

The types composing the Gangamopteris flora belong, as Professor Arber[1] has so well shown, almost exclusively to families already well known in the cosmopolitan flora. They constitute genera or species more or less closely bound to their northern relatives, though often differing much in form and aspect. In general they appear simpler in figure, with a tendency to thickness and rugosity of leaf that may indicate either a xerophytic or pseudoxerophytic condition. On the whole the aspect of the plants distinctly suggests environmental conditions unfavorable to luxuriant plant growth. That the development of this flora was directly consequent to a Permo-Carboniferous period of regional refrigeration is now no longer questioned. In its purest and simplest composition, and with remarkable uniformity, it is found in India, Austraila, South Africa, and South America immediately above apparently contemporaneous formations bearing evidence of the work of ice. The conditions which brought the new flora into being banished or exterminated the Cosmopolitan or northern Permo-Carboniferous flora from the Gangamopteris province. The early return of a few of the hardier Lycopodineous forms in Argentina, Brazil, and South Africa, has already been mentioned. Most of the former plant population of the province died in exile, and only their posterity, especially among the Cladophleboid ferns and the Araucarian, Ginkgoalean and Cycadalean gymnosperms were able to traverse the lost territory and contest the Gangamopteris occupation.

It is not probable that any serious hindrance other than altitude or climate seriously opposed the return of the northern flora to the Gangamopteris province in either the Western or the Eastern Hemisphere. The early return of certain Lepidophytes to the Brazilian and South African regions and the invasion of the Russian area by some of the older Gondwana elements is evidence of the efficiency of the land route. The absence of the northern flora from the series above the glacial deposits can therefore be due only to the uncongeniality of the province to that flora.

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[1] *Catalogue of the Foss. Pl. of the Glossopteris Flora in the Department of Geology in the British Museum,* 1905, p. xx.

CAUSES OF THE PERMO-CARBONIFEROUS GLACIATION

So varied as well as great are the geological changes since Paleozoic time that the exposure, at this late date, of an ancient glaciated floor at even a few points is fortuitous. Yet proofs of Permo-Carboniferous land ice movement have been observed over an area more than 800 miles in length and 400 miles in breadth in South Africa,[1] while glaciated material is seen here and there over a very much larger territory. In Victoria the till and bowlder beds compose the greater part of a section about 1,700 feet in thickness. Bedrock striation, the work of grounded icebergs, if not of subaerial ice, is seen in India, and several provinces of Australia as well as in Tasmania. The GANGAMOPTERIS province undoubtedly witnessed Permo-Carboniferous glacial action many times greater than that which occurred in the Northern Hemisphere during Pleistocene time.

However complete the unanimity as to the fact of Permo-Carboniferous glaciation in the GANGAMOPTERIS province, there is little agreement as to the causes of that remarkable episode. The information obtained from South America both extends and defines more clearly the problem, though in the solution of the latter the testimony of the new data is perhaps chiefly negative.

So long as the glaciation was supposed to have been confined to the Indo-Africo-Australian quarter of the earth a shifting of the axis so as to place the pole in the Indian Ocean was urged in explanation of the regional refrigeration. The recognition of the glaciation in South America and as far north as latitude 28° in that continent seriously modifies if it does not completely destroy this hypothesis.

Depletion of atmospheric carbonic-acid gas.—Of the other hypotheses that which seems by far most nearly to meet the situation has for its essential condition loss of heat on account of a depletion of the atmosphere in carbonic dioxide consequent to great coal and limestone deposition during the Carboniferous epoch. Co-operative and almost co-ordinate with this atmospheric impoverishment were, in the judgment of the writer, the size and height of the glaciated land masses.

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[1] Wm. M. Davis, *Bulletin of the Geological Society of America*, Vol. XVII, 1906, p. 377.

That there was a change in the composition of the atmosphere toward the close of the Carboniferous is now generally admitted. Whatever may have been the effect of the limestone deposition, it is certain that the carbon extracted from air and sea and stored away in the coals and bituminous shales of the Paleozoic Coal Measures was far greater in amount than that in any other similar series laid down during geological time. Abundant red beds and oxidation bear evidence of the concomitant high proportion of oxygen in the atmosphere and of rapid evaporation.

Great extent of southern lands.—Concerning the size of the land masses the testimony is hardly less clear. It has been shown that the conditions of land plant and land vertebrate distribution call for the extension of land surfaces in one continuous or in several nearly contiguous continents including large portions of India, Australia, New Zealand, South Africa, and southern South America. It is probable that this connection was accomplished through the medium of an Antarctic continent, of which Australia, South Africa and a part of South America were possibly but lobes. The surviving or vestigial areas preserved in India, Africa, and South America bear evidence of the existence of enormous drainage surfaces on which the great series[1] of conglomerates and coal measures of the Gondwanas in India, the Dwyka and Ecca series in South Africa, and the Permo-Carboniferous of many states in Argentina and Brazil were laid down as fresh-water formations. The magnitude of the land ice action itself argues for extensive land surfaces in those regions.

Problem of tropical glaciation.—The most difficult feature of the problem relates to the geographical distribution of the glacial evidence. In India distinct ice work is found at 18° N.—i. e., within the tropics—and bowlders regarded as glacial have been found at 32° N., in the Salt Range. The Australian region within which glacial material is found extends from 20° 30′ S. to 42° S., and ranges through about 35° of longitude. In South Africa glacial material has been found from 25° to 33° S. and through 11° east and west, while in South America it appears to occur as far north as 30° S. In Australia there is proof of a recurrence of glaciation with a thin interglacial series (Greta), 230 feet in thickness including coals, between the bowlder beds.

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[1] In South Africa 4,000 feet; about 10,000 feet in New South Wales; 1,200 feet of the Talchic conglomerate, while the Damuda series alone is said to measure 10,000 feet in India.

Exaggerated temperature effects of elevation.—The occurrence of glacial phenomena within the tropics was presumably due in part to an extension of the southern cold with the favoring assistance of ocean currents and perpetual atmospheric "lows," resulting in part from continental relations and topography. The writer is strongly disposed further to attribute a very important part in the refrigeration, and more particularly the singular localization of the latter, to the height of the land on which the glaciers developed. Mention has already been made of the fact that the great coal measures series of the Gondwanas, of South Africa, and of South America are vast fluviatile or lacustrine deposits many thousands of feet in thickness, resting unconformably on old erosion basin floors. The enormous accumulations of coarse conglomeratic material in the eastern regions testify to the steep gradient of the drainage systems. The presence in nearly all regions of the great unconformity is itself evidence of the vigor of the post-Carboniferous uplift in the GANGAMOPTERIS province. In Africa and South America, at least, large portions of the land masses probably stood at a considerable elevation during glaciation. It is not clear that in Australia or India the source of the ice was near sea level, though on both the latter there is abundant evidence of the deposition of bowlders dropped from floating ice. Currents of cold water sweeping along the Antarctic continent may well have carried icebergs for long distances to the north in the Australian region.

A relatively high altitude for the areas of ice accumulation would not only enormously assist in explaining the peculiar geographical distribution of the ice phenomena, but it would seem to offer a satisfactory accounting for the differences in climate, as indicated by the floras, between the Northern and Southern regions. It has been urged by Chamberlin[1] that a diminution of the CO_2 of the atmosphere, with its attending decrease of humidity, would result in a marked increase in the difference between the mean temperatures of land and sea, the loss of the sun's heat by the land being greatly accelerated as compared to the lesser loss by the sea; so that despite stronger winds, convection currents, etc., an increasing cold would prevail in the greal land areas. If to this principle is added a most important fact, that altitudinal differences in temperature would be exaggerated if the carbon-oxide of the atmosphere were reduced, it will appear probable that partial depletion of the carbonic acid gas might produce greatly magnified effects of cold, with accentuated seasonal differences at relatively moderate elevations in the interiors of the land masses,[1] while the climate near sea level especially in the smaller lands or in proximity to large oceanic bodies, might still be mild and relatively equable. It might thus be possible for the Cosmopolitan flora to survive on the low or base-leveled coasts of the sea-girted northern lands while glacial conditions prevailed at no great elevation in the interior plateaus and subaerial basins of the Southern "Gondwana-land." The writer is therefore disposed to believe that the glaciation in the GANGAMOPTERIS province was secondarily due to the elevation of its land masses to greatly reduced refrigerative altitudes at the time of the post-Carboniferous uplift. The elevation of the southern land masses and their erosion and glaciation are fully demonstrated. The enormous thickness of continental sediments already noted in Africa, India, and Australia, including over 1,200 feet of basal conglomerates alone, is itself evidence of a considerable height of land. In Australia there was probable oscillation and recurrence of glaciation as shown by the intercalation of the Greta coals and shales, the latter inclosing the pure GANGAMOPTERIS flora.

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[1] *Journal of Geology,* Vol. VII, 1899, pp. 545, 667, 751.

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[1] The accelerated decrease of temperature in ascending the atmospheric column occasioned by reduction of CO_2 is remarked by Chamberlin. Granting that carbonic acid gas in the atmosphere exerts the influence in arresting the outgoing heat rays attributed to it by Arrhenius and Chamberlin, it is plain that, on account of the extension of its zone far above that of the humidity, an increase or reduction of its volume must also directly and strongly affect the differences in temperature due to differences of altitude. With reference to the climatic effects of changes in the proportion of CO_2 in the atmosphere, the reader is referred to the most valuable discussion published by Professor Chamberlin in Vol. VII of the *Journal of Geology*, 1899, or the second volume of the *Geology* published (1906) by that author in collaboration with Professor R. D. Salisbury.

SURVIVAL OF NORTHERN, "COSMOPOLITAN," TYPES

The survival, in the northern province, of the Cosmopolitan, Carboniferous flora, which had been exterminated from the greater part, at least, of the GANGAMOPTERIS province, and its metamorphism to the Cosmopolitan Permian flora, was presumably due to the generally low base-leveled state of the northern lands and the growth of the plants near tide level in regions bordering great bodies of water. The greater retention of the sun's heat by the sea and the greater humidity would co-operate with the low altitudes to neutralize the effects of atmospheric carbonic acid reduction. The contrast with the climate of the basins in the interior of the more elevated GANGAMOPTERIS (Antarctic) continent could not fail to be great. It is worthy of note in this connection that in general the floral changes in passing to the Permian are least marked, the number of surviving later Carboniferous species being greatest, in those northern regions in which the post-Carboniferous uplift was least and there was less withdrawal of the sea. The best-marked illustration of this is furnished by the Appalachian trough in which the floral change is relatively gradual, the more characteristic Permian species being probably migrant from some more strongly affected region. The early moderation of the climate in Brazil so as to permit the return of a few hardy northern types and the enlargement of the GANGAMOPTERIS flora in other regions by the mingling of northern derivatives were presumably due to subsidence under loading of the basins; the general extension of the marine surface in the upper Permian; and, possibly, to a direct carbonic acid contribution attending the great vulcanism of the Permian.

The flora of the Upper Permian is known in but few parts of the earth, but it is found that early in the Zechstein GANGAMOPTERIS and northern Permian elements mingled in the basins of northern Russia and the Altai; the northern Cycad, Pecopteroid, and Coniferous elements had already invaded the GANGAMOPTERIS province, and from this mingling was developed a group which survived as the nucleus of a new world-wide Cosmopolitan flora, that of the Older Mesozoic.